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Planning for long-duration space exploration: Interviews with NASA subject matter experts

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ABSTRACT

Planning is critical to organizations, especially for those involved in pursuing technologic, scientific, and innovative ventures. Examination of planning processes is particularly important in high-stake and high-risk environments. In the present study, to highlight the significance of planning in the context of long-duration space missions, 11 current and former National Aeronautics and Space Administration (NASA) personnel were interviewed to gain a better understanding of astronaut and Mission Control leadership in preparing for and carrying out space missions. Interviewees focused their responses on perceptions of leadership and thoughts on how long-duration spaceflight leadership should be different from current and short-term spaceflight. Notes from these interviews were content coded and qualitatively analyzed. We found that cognitive planning skills and case-based reasoning were among the variables that were most highly rated for being critical to the success of long-duration space missions. Moreover, qualitative analyses revealed new considerations for long-duration space missions, such as granting greater autonomy to crewmembers and the need for more near-term forecasting. The implications of these findings for understanding the planning processes and necessary characteristics of individuals tasked with planning are discussed.

1. Introduction

Planning is of paramount importance for organizational performance, especially in organizations that pursue scientific, technologic, and innovative endeavors. In fact, the complexity and challenging nature of these pursuits that typically occur in dynamic, rapidly changing, and uncertain contexts and environments necessitates planning [1,2]. Examining planning in the context of NASA and long-duration space missions is an effective means of highlighting the criticality of planning. Long-duration space missions (e.g., missions to Mars) present unprecedented levels of complexity, risk, and uncertainty. NASA has never faced the unique challenges that come with indeterminate and long-duration space missions. The resources required of both Mission Control and the astronaut crew to successfully complete a mission of this magnitude are vast. Moreover, the success of long-duration space missions is not only vital for the lives of those crewmembers on the spacecraft, but for the continued support of NASA by the government and people worldwide. To ameliorate the likelihood of a successful mission of such enormity, NASA could benefit from prioritizing planning before and during long-duration space missions.

Prioritizing planning can benefit not only NASA, but can benefit other organizations faced with similar, high-stakes, and unpredictable situations and environments. The individual characteristics of those who engage in planning and the planning process variables critical to successful long-duration space missions can serve as a reference point for these organizations tasked with handling a major change event requiring extensive planning. Failure to plan when undergoing change could result in sub-optimal outcomes. Furthermore, the findings emerging from this study regarding the criticality of planning for long-duration space missions can help inform planning for similar high-risk contexts by bringing attention to the more important planning processes and highlighting the important characteristics needed for those selected to be involved in the planning process.

As such, the purpose of this article is to bring to fore shifts in perspective regarding planning for long-duration space

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exploration and to identify planning processes important for long-duration missions, as well as individual attributes that will contribute to effective planning for such missions. To accomplish this, we examined the past and present culture of NASA as it relates to planning, and highlight potential issues identified by current and former NASA personnel. More specifically, one-on-one telephone interviews were conducted with astronauts, flight directors, capsule communicators (CAPCOMs), flight controllers, and operational support personnel. Interviewees answered questions related to key phases in preparing and planning for long-duration space missions, differences in opinion among NASA personnel, and unanticipated events that might occur on long-duration missions. Using the notes taken from these interviews, key planning variables and individual characteristic variables important to planning [3,4] were rated by planning experts on a 5-point Likert scale for the extent to which the interviewee viewed the variable as important to the success of long-duration space missions. Means and standard deviations were calculated for each of these variables. Key themes were also extrapolated from the notes taken during these interviews for comprehending what current and former NASA personnel think should be done differently in preparing for long-duration space missions. Moreover, our research questions helped inform the identification and selection of these themes upon reading through the interview notes multiple times.

2. Historical planning at NASA

The incident involving Apollo 13 is a quintessential example of NASA's past planning culture [5]. A domino effect of personnel and technical issues resulted in an adverse situation for both Mission Control and the crewmembers aboard Apollo 13. The initial crew assigned to the mission ran simulations before launch to familiarize the astronauts with one another's personalities and working styles. Only a few days before the mission, the crew was exposed to measles, resulting in the replacement of the command module pilot. This unanticipated member change was only the beginning of what would become a series of foreseeable crises.

During the mission, several technical issues arose that had not been anticipated before mission launch. To start, ground tests indicated the possibility of a poorly insulated helium tank in the lunar module, resulting in the decision to alter the flight plan. Five minutes after liftoff, the center engine shut down 2 min early, which resulted in the other engines burning 34 s longer than was planned [6]. Manufacturing issues occurred with the oxygen tanks, and one oxygen tank exploded during the mission, causing the second oxygen tank to fail. As a result, oxygen levels started to drop on the spacecraft, while CO_2 levels increased. To further exacerbate the situation, the command module's normal supply of light, electricity, and water was lost. It seems appropriate to speculate that initial oversights may have had a direct impact on the likelihood of subsequent spacecraft issues. Had more of the potential issues before and during spaceflight been considered, more of the dangers experienced on the Apollo 13 mission may have been avoided.

The Apollo 13 mission was considered a “successful failure” by NASA [7], which ultimately resulted in the organization-wide mindset that failure is not an option. Although all crewmembers on Apollo 13 made it safely back to Earth, it is important to bear in mind NASA's lack of backup plan development for potential crises before launch. Failure should not be looked upon as an organization-wide disaster; but rather, it should be looked upon as an opportunity to devise and implement backup plans. Furthermore, the sequence of events that occurred during the Apollo 13 mission should serve as an impetus for NASA to predict potential near-term issues before launch.

Long-duration space missions, such as a mission to Mars, differ greatly from short-duration space missions, especially in terms of length and complexity. Moreover, a mission to Mars entails dynamic, dangerous, and high-pressure situations in a confined space. There will be times of high stress and activity, yet there will also be times of boredom and downtime during the roughly 3-year mission [8]. This variability in activity is coupled with the challenges of human factors and medical support issues and the risk of several physiologic effects. The physical and social environment inherent to a long-duration space mission provides a sharp contrast to that of a short-duration mission, such as the Apollo 13 mission. The riskiness, unpredictability, and extreme nature of a mission to Mars highlights an even greater need to plan for long-duration space missions. We now turn to the literature on planning to identify the key stages and processes involved in plan development. We will then compare and contrast historical planning with the modern planning culture at NASA resulting from past spaceflight challenges.

3. Planning

Planning is the mental simulation of an action or course of actions with respect to the attainment of certain outcomes [3,9,10]. More specifically, plans are based on setting goals and the contingencies that apply to the attainment of these goals [11]. Moreover, complex and dynamic contexts, such as those experienced in long-duration space missions, may attenuate or impede this path to goal attainment [12]. Regarding the results of effective planning, we know that planning provides structure, enables quick action responses, and ensures that required resources to attain goals will be available [10,13,14]. Additionally, planning facilitates the identification and evaluation of information, in addition to assisting adapting to change [15]. It is evident that planning contributes to performance when faced with difficult tasks and uncertain or unstable environments and situations.

Multiple, interconnected processes are involved in planning. These processes include idea generation, projection and revision, and implementation [3,16,17]. During the idea generation stage, the environment is monitored for changes, and the needs pertaining to the situation are addressed. Goals are then generated and specified. Once goals have been formulated, the key actions required to reach these goals and the restrictions impinging on these goals are identified. During the projection and revision stage of planning, causes and contingencies are identified, and the consequences of implementing the plan in the current context are contemplated. Once consequences are taken into account, a more refined plan is then produced. During the implementation stage of planning, key marker events are used to guide environmental monitoring. Then, backup plans are developed and resources needed to develop these backup plans are acquired. Furthermore, backup plans should be generated to take into account problems or crises that arise when monitoring the environment. Throughout the entire planning process, the plan is periodically reevaluated and adjusted as critical events and changes emerge. Elements of the planning process that prove to be highly successful or unsuccessful are then abstracted for future use in the development of plans of a similar nature. Moreover, there is evidence lending support to the importance of flexibility and adaptability in planning [18], hence the need for adaptive planning to be present throughout long-duration space missions.

3.1. Planning processes

Mumford, Schultz, and Osburn [3] developed a planning model, depicted in Fig. A.1, that underscores the key processes involved in